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# ASSESSMENT OF THE EFFECTIVENESS OF WRONG-WAY DRIVING (WWD) DETECTION SYSTEM

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16. Abstract

Wrong-way Driving (WWD) presents one of the most serious traffic hazards on the highway system across the United States. According to the data from the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS), hundreds of fatal crashes are caused by WWD drivers yearly. This issue remains unsolved at many locations due to the high cost of installing and maintaining WWD prevention systems. Hence, a more cost-efficiency method to utilize the current infrastructure to identify the incident of WWDs and then find proper countermeasures. In this project, our research team aims to utilize the radar sensor data for WWD incident detection, using detected negative vehicle speeds as a basis. However, it shall be noted that the obtained datasets often contain false pulses and inaccurate detection information. To overcome this problem, this study proposes a screening algorithm for identifying the WWD incidents and potential WWD false alarms based on over 18-month data from the Utah Department of Transportation (UDOT). The algorithm contains three primary steps, preliminary data quality evaluation, threshold-based data assessment, and probability-based data screening. The algorithm is calibrated based on Utah police WWD records. Finally, the algorithm is implemented on three freeway segments in Salt Lake City area for a demonstration.

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## LIST OF ACRONYMS

| | |
|---|---|
| NTSB | National Transportation Safety Board |
| WWD | Wrong-Way Driving |
| FHWA | Federal Highway Administration |
| NHTSA | National Highway Transportation Safety Administration |
| LED | Light-Emitting Diodes |
| UDOT | Utah Department of Transportation |
| AEVL | Average Effective Vehicle Length |
| TOC | UDOT Traffic Operation Center |

# EXECUTIVE SUMMARY

Wrong-Way Driving (WWD) presents one of the most serious traffic hazards on the highway system across the United States. According to data from the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS), hundreds of fatal crashes are caused by WWD drivers yearly. This issue remains unsolved at many locations due to the high cost of installing and maintaining WWD prevention systems. Hence, a more cost-efficient way is to utilize the current infrastructure to identify incidents of WWD and then find proper countermeasures. In this study, our research team proposed a screening algorithm for identifying WWD incidents and potential WWD false alarms by utilizing over 18 months of sensor data from the Utah Department of Transportation (UDOT) and Utah police WWD data.

The proposed algorithm uses detected negative vehicle speeds as its basis, which includes three primary steps. In the first step, a preliminary data quality evaluation is performed on the information obtained from selected sensors. Then a threshold-based assessment process is implemented for identifying potential WWD false alarms. In the last step, a probabilistic model is developed for final screening. In this project, we calibrated the parameters of the proposed algorithm with the police daily shift report. To verify the effectiveness of the proposed algorithm, three case studies were conducted to investigate the WWD high-incidence time range and high-risk highway segments.

Results of case studies revealed that the proposed algorithm can function well to identify WWD incidents and potential WWD false alarms on the transportation network and to notify responsive agencies such as the state DOT which locations need additional countermeasures. The results also showed that most WWD events happen in the late night and early morning when the traffic volume is low. It further indicated most wrong-way drivers enter the highway from the off-ramp and don’t drive far from the off-ramp (most within 0.5 miles of it).

# 1.0 INTRODUCTION

## 1.1 Problem Statement

The National Transportation Safety Board (NTSB) defines wrong-way driving (WWD) as vehicular movement along a travel lane in a direction opposing the legal flow of traffic on high-speed divided highways or access ramps (Report eta Board, 2005). A WWD crash is one when a traveling WWD vehicle collides with another vehicle traveling on the same roadway in the proper direction (FHWA, 2016). WWD presents one of the most severe traffic hazards on national highway systems. Although collisions caused by WWD are infrequent (approximately 3 percent of total crashes on freeways) compared with other types of crashes, they often result in fatal or serious injury to the persons involved since most WWD crashes are head-on or opposite direction sideswipe crashes with high speed. According to the Federal Highway Administration (FHWA), 300 to 400 people are killed annually due to WWDs in the United States (Brevoord, 1984). Based on the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS) database, an analysis of crash data (2004 to 2014) showed that about 350 people are killed from approximately 270 fatal crashes each year due to WWD (Baratian-Ghorghi et al., 2014). Several existing studies have also shown that impaired driving and confused driving are the two primary reasons that lead to WWD related crashes (Report eta Board, 2005; Simpson eta Bruggeman, 2015). The causes of impaired driving include drowsiness, drugs, alcohol, distractions due to mobile devices, and medications. The confused driving can be attributable to poor ramp design, poorly marked ramps, insufficient signs and/or visibility. Therefore, it is critical to leverage sensors to detect WWD immediately upon occurrence, notify the traffic management center and public safety dispatcher of the wrong-way entry point, and inform the wrong-way driver of their mistake.

Besides the implementation of a WWD detection system, a lot of research activities have focused on quantifying the WWD impact and assessing countermeasures and mitigation methods. Some traditional countermeasures for implementation include enlarged Wrong-Way signs, red reflective sheeting on sign supports, Wrong-Way signs with flashing light-emitting diodes (LEDs) around the border, pavement marking, and ramp design re-configuration.

However, which countermeasures can be most effective for wrong-way drivers, and are effective at getting them to correct the mistake (e.g., stop or turn around) remains an open question.

The Department has been installing Wavetronix since the mid-2000s. Prior to 2016, detection records were binned on 20 second intervals in the sensor while individual vehicle detection records have been recorded starting from 2016. The system was deployed over 18 months and the detection records revealed many negative speeds in the obtained database. At the same time, police crash reports showed that a large amount of collisions were caused by impaired driving. Hence, it raises a critical question of whether UDOT can use the negative speed records to indicate WWD events. In practice, radar sensor-based WWD detection systems often have the following two problems: 1) Missed Call: System failed to detect a wrong-way vehicle; and 2) False Detection: A positive detection occurred without the presence of a wrong-way vehicle. To address those problems, our research team at the University of Utah will assist UDOT in developing a screening algorithm to identify potential missed calls and false detections by the current system. This algorithm will be implemented on the freeway segment in the Salt Lake City area. Further policy-driven analytics will be conducted to understand the primary reasons that lead to WWD-related collisions. At locations with high WWD collision frequency, we will assess the current countermeasures adopted by UDOT and discuss potential improvement for WWD mitigations. Proposed research tasks in this project will be presented in the following section.

### 1.2 Objectives

The primary objective of this study is to utilize radar sensor data for detecting WWD events, using negative speeds of individual vehicles as indicators of WWD events. Based on data from the police daily shift report, our research team will develop a screening algorithm for eliminating false alarms, then the radar sensor data can effectively detect WWD incidents on the freeway network. The results will help responsive agencies, such as state DOTs, identify the locations that need immediate attention.

## 1.3 Scope

This study offers a cost-efficient method to identify WWD incidents by developing a data screening algorithm to identify WWD false alarms (i.e., false negative vehicle speed detections) from radar sensors. The proposed algorithm includes three primary steps. In the first step, a preliminary data quality evaluation is performed to target the sensors. Then a threshold-based assessment process is implemented for identifying potential WWD false alarms. In the last step, a probabilistic model is developed for final screening.

## 1.4 Outline of Report

This report documents the findings of the research and proceeds with the following sections:

- Literature Review
- Data Description
- Data Screening Algorithm
- Algorithm Parameter Calibration
- Experiment of Algorithm
- Countermeasures
- Conclusion

# 2.0 LITERATURE REVIEW

## 2.1 Overview

In this study, our research team aims to utilize radar sensor data for WWD incident detection using detected negative vehicle speed as its basis. However, the obtained datasets often contain false pulses and inaccurate detection information. To overcome this problem, this study further proposed a screening algorithm for identifying potential WWD false alarms based on over 18 months of data from the Utah Department of Transportation (UDOT). By comparing the results with Utah WWD police records, the examples have proved the correctness of the proposed algorithm and further evaluations are conducted on freeway segments in Salt Lake City. Consequently, the literature review conducted for this research focuses on the following areas:

- Existing studies focused on using detectors for the WWD problem
- Existing studies focused on screening detection errors

## 2.2 Existing Studies Focused on Using Detectors for the WWD Problem

Several existing studies focused on using detectors for the WWD problem. Simpson and D. Bruggeman (2015) tested a wrong-way detection and warning system to detect wrong-way driving, immediately warn drivers of their error, and notify the traffic management center when a wrong-way vehicle passes through the detector. Vanysek et al. (2005) introduced how to use radar detectors to collect wrong-way driving data and how to enhance system reliability, which mainly uses computer programming software to make sure that the detector of each site can properly detect vehicles at all times. Simpson (2013) accesses five different wrong-way driving detection technologies including microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors, and mainly shows the effectiveness of each detection system through installing each one on a specific road in the Arizona area.

## 2.3 Existing Studies Focused on Screening Detection Errors

Many existing studies focused on screening detection errors have been reported as early as the 1970s. Sanchez (2016) evaluated the accuracy of approach volumes and free-flow approach speeds collected by the Wavetronix Smart Sensor. By statistically analyzing ground truth volume counts and vehicle approaching speeds, the study identified significant factors that can affect the accuracy of the detector, such as sensor position, level of traffic volume, number of approach lanes, and lane position. Chang et al., (2017) employed a mixed variance analysis model and showed that factors such as volume level and number of approach lanes have statistically significant effects on the detection accuracy of traffic volume counts collected by microwave sensors. Several other studies have adopted average effective vehicle length (AEVL) to identify detector errors (Achillides eta Bullock, 2004; Lu et al., 2014; Turochy eta Smith, 2007). For example, Lu and Yang (2014) evaluated the data quality of a target detector by comparing the estimated AEVLs between lanes and stations. Turochy and Smith (2007) applied traffic flow theory-based tests by using AEVL to represent inherent relationships among speed, volume, and occupancy for detecting erroneous data.

# 3.0 DATA DESCRIPTION

Wavetronix have been installed on Utah highways since the early 2000s. From 2016, Wavetronix radar sensors (one detection station per 2-3 miles) along major freeway segments started recording individual vehicles in Utah and UDOT started bringing individual detection errors back from the sensors for storage. The system has been deployed for almost 3 years (7/2016-now) and all obtained data are stored and managed by UDOT's Traffic Operations Center (TOC). After a preliminary data analysis, many sensors have shown negative speeds of individual vehicles which indicate potential occurrences of WWD incidents. In addition, a police daily shift report has recorded all reported WWD events during 7/2016 – 1/2018 with the corresponding times and locations. In summary, there are 173 WWD records in total and the time distribution is shown in Table 3.1. By comparing the daily shift report information with radar sensor data, it can be observed that some police recorded WWD incidents are not detected by the sensors (i.e., no negative speed found), which indicates possible "missed calls". However, the remaining records can be treated as ground truth for calibrating and validating the proposed algorithms.

**Table 3.1 Number of WWD incidents at different times of day**

| Time of the day | Number of WWDs | Percentage |
|---|---|---|
| 00:00am - 06:00am | 42 | 24.86% |
| 06:00am - 12:00pm | 31 | 17.92% |
| 12:00pm – 6:00pm | 37 | 21.39% |
| 8:00pm – 12:00am | 63 | 36.42% |
| Total | 173 | 100% |

In this study, sensor data was obtained from UDOT's "Freeway Performance Metrics" database. The occurrence data involves the attributes of "time", "LaneID", "Direction", "Speed", "Length of vehicle", and "Duration" of each detected vehicle.

# 4.0 SCREENING ALGORITHM

## 4.1 Overview

Because detected negative speeds could be an indicator of WWD events, the proposed screening algorithm for identifying potential false pulses consists of the following three steps:

Step 1: Check the existence of negative speeds and preliminarily evaluate data completeness and correctness.

Step 2: Identify potential false negative speed pulses using a set of pre-defined thresholds for comparisons.

Step 3: Estimate a vehicle's probability of traveling from off-ramp to detected location without encountering other opposing vehicles.

## 4.2 Step 1: Preliminary Data Check

At this step, the proposed algorithm will go through the following preliminary data checks:

- *Data completeness and negative speed check*:
  The targeted radar sensor shall provide valid occurrence data which include detection time, lane ID, vehicle direction, speed, length of vehicle, and detector-occupied duration. In addition, one shall check whether negative speed exists in the dataset during the study period. If no negative speed is found, there is no need to conduct further screening.
- *Nearby sensor station check*:
  WWD vehicles may be detected by multiple sensor stations on the freeway. If a sensor station exists between the target one and a nearby off-ramp, one shall cross-verity whether both sensor stations detect negative speed. If yes, the corresponding negative speed could be labeled by "Not false alarm"; otherwise, further screening is required.

- *Vehicle characteristic check*:

  The detected negative speed, length of the vehicle, and occupancy duration shall lie within reasonable ranges. If not, the target record can be labeled by "Potential false alarm". Notably, the ranges may vary by locations.

### 4.3 Step 2: Threshold-Based Screening Algorithm

After the completion of step 1 screening, step 2 further compares the characteristic of the target negative speed record with a set of pre-set thresholds. Notably, WWD usually happens at uncongested freeway segmens and WWD vehicles generally do not travel a long distance. Hence, the threshold-based screening algorithm mainly focuses on the examination of three factors including "time of day", "distance to the ramp" and "traffic volume". The detailed process of screening is shown as follows:

- *The threshold of WWD occurring time*

Most WWD events happened during night time since they tend to be in low traffic flow and dark conditions (Ponnaluri, 2018). The majority (71%) of WWD crashes occurred in night-time (dark) conditions (Lin et al., 2018). 90% of WWD collisions happened during night time (12:20 p.m. - 3:07 a.m.) in the Sacramento and San Diego Regions in 2015 (California-business et al., 2016). Almost 70% of wrong-way collisions occurred during night time from (8:00 p.m. - 6:00 a.m.) (Doctor, 2016). Based on these existing studies and first-step screening algorithm results, a threshold-based screening on WWD occurrence time can be represented by the following expression:

$$a \leq T \leq b \tag{1}$$

where *T* is the WWD occurrence time; *a* is the earliest time of occurring WWD incidents, and *b* is the latest time of occurring WWDs.

- *The threshold of distance to the off-ramp*

WWD incidents and consequent crashes tend to happen close to ramps (FHWA, 2016; Lin et al., 2018; Report eta Board, 2005). Most WWD vehicles enter the highway via off-ramps, generally do not move too far on the highway from the off-ramp as the drivers may realize they are traveling in the wrong direction, or they may quickly encounter opposing vehicles. Based on existing studies and results of step 1, one can get the following formula to represent the threshold of the distance to the ramp:

$$0 \le D \le s \text{ miles} \tag{2}$$

where $D$ is the Distance from the detector to the ramp; and $s$ denotes the maximum possible WWD travel distance.

- *The threshold of traffic volume*

In practice, WWD occurs frequently when freeway traffic volume is low (Brevoord, 1984; Ponnaluri, 2018). As reported in the literature, 100% of WWD incidents happened when the freeway volume was less than 140 veh/5 min (Das et al., 2018). Hence, based on existing studies and the results of step 1, one can set the threshold of traffic volume as follows:

$$0 \le q \le Q \text{ veh/5 min} \tag{3}$$

where $q$ is the 5-min traffic volume when WWD happens; and $Q$ denotes the maximum 5-min traffic flow on a specific lane with negative speed.

### 4.4 Step 3: Probabilistic screening model

As step 2 mainly uses pre-set thresholds for identifying potential false pulse, it requires sufficient field data to calibrate those thresholds. Also, it has limitations on dealing with outliers in the dataset. To overcome this problem and improve screening accuracy, this study further develops a probabilistic model in this step.

In real-world applications, traffic radar sensors may be placed on the freeway mainline, as shown in Figure 4.1(a), or freeway ramps, as shown in Figure 4.1(b). If a detected negative speed is real (i.e. not a false alarm), the WWD vehicle generally does not encounter opposing vehicles during the time of traveling from the end of the off-ramp to the location of the detector.

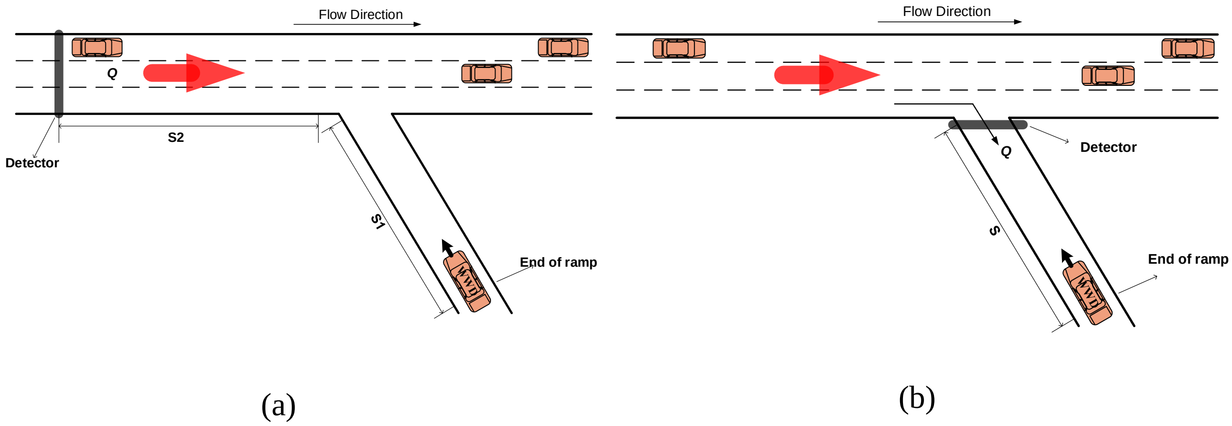


**Figure 4.1 Two Types of Detector Location for WWD Detection**

Hence, given the incoming traffic flow rate, one can estimate the probability of WWD vehicles traveling to the sensor location without crashing into opposing traffic. Considering WWD events often happen under light traffic conditions, this study assumes the traffic arrival pattern follows Poisson distribution:

$$\mathrm{P}(\mathrm{X}=x)=\frac{e^{-\lambda}*\lambda^{x}}{x!}\quad x\ =\ 0,1,2,3,4,\ldots \tag{4}$$

$$\lambda=\frac{SQ}{v} \tag{5}$$

where $P$ is the probability of numbers of WWD vehicles confronting $x$ opposing vehicles; $X$ is the number of vehicles arriving at a detector before WWD arriving at the detector; $\lambda$ is the expected number of vehicles coming from upstream; $Q$ is the traffic flow rate; and $S$ is the distance from the off-ramp to the sensor location. Notably, in the cases of Figure 4.1 (a) and (b), one shall use the upstream volume and off-ramp exiting flow rates, respectively, for calculations.

Considering a WWD vehicle may change lanes on the freeway mainline, the proposed algorithm would examine its probability of confronting “zero”, “one”, and “two” vehicles. If the calculated probability is less than a pre-set threshold, the algorithm will label the studied negative speed record as “potential false alarm”; otherwise, it will be labeled as “not false alarm” and can be used for identifying WWD incidents on the freeway network.

In summary, the flowchart of the proposed WWD false alarm screening algorithm is illustrated in Figure 4.1.

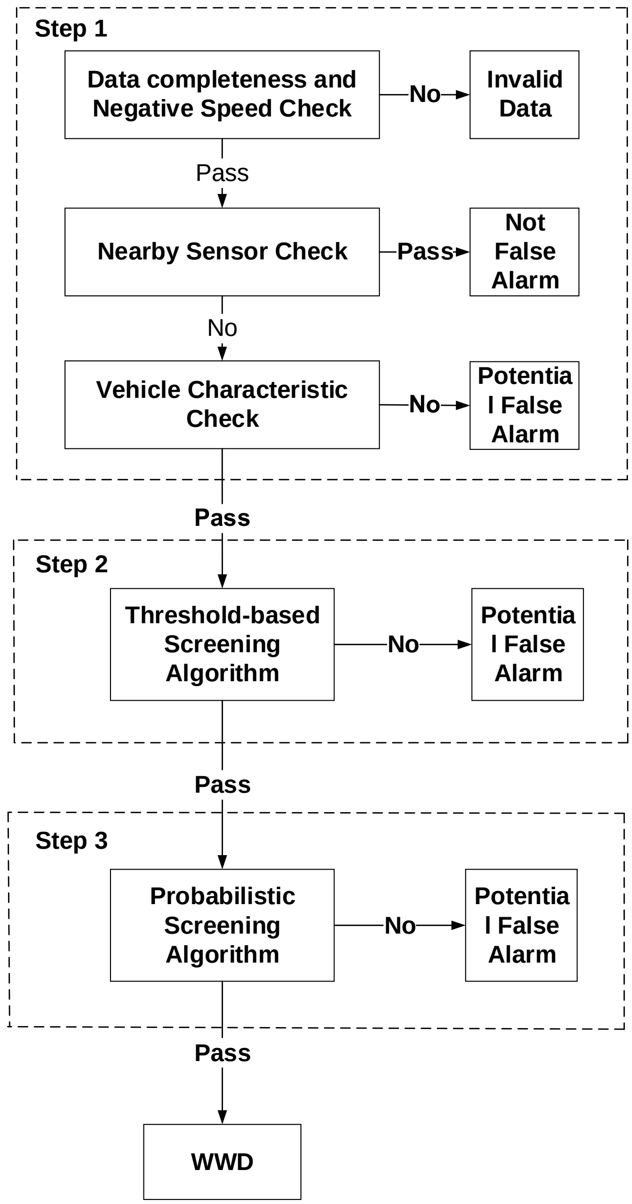


**Figure 4.2 Flow Chart of Screening Algorithm**

## 5.0 ALGORITHM PARAMETER CALIBRATION

The proposed screening algorithm consists of three primary steps where the second and third step contains some parameters that need calibration with field data. Specifically, in Step 2, those parameters include the threshold of occurring time, the threshold of distance to the off-ramp, and the threshold of traffic volumes. In this study, our research team adopts the Utah police daily shift report during 7/2016 – 1/2018, which contains 173 WWD records, to determine the values of those parameters.

**Table 5.1 Distribution of Detector Data for WWD Records**

| Data Completeness for WWD records | Number of WWD Records | Percentage |
|---|---|---|
| No station | 39 | 22.54% |
| Station with no data | 37 | 21.39% |
| With data and with a negative speed | 94 | 54.34% |
| With data and no negative speed | 21 | 12.14% |
| Total | 173 | 100% |

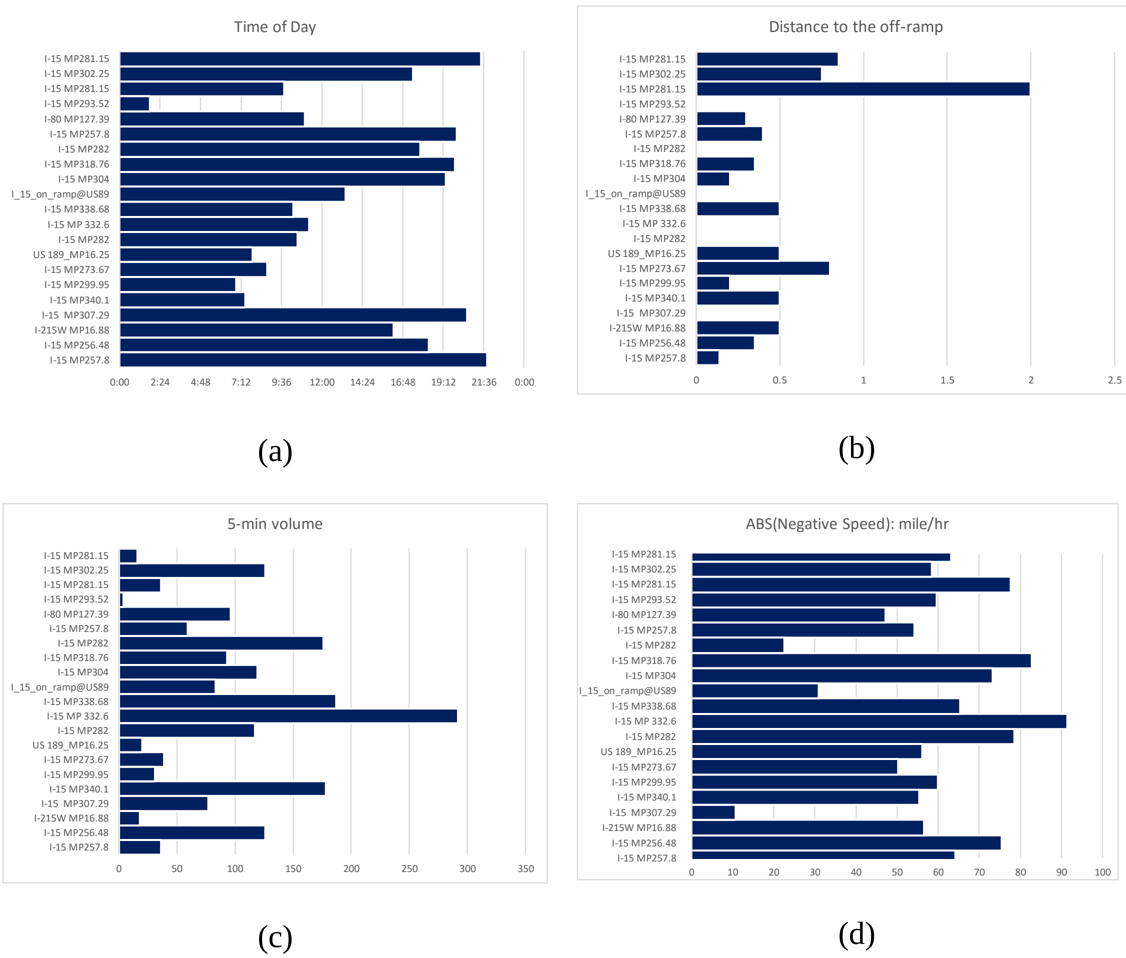


**Figure 5.1 Spatial Map of Nearby Detector**

Based on the recorded time and location of each WWD event in the report, we have retrieved the corresponding occurrence data from UDOT's Freeway Performance Metrics database. The results of cross-verification between the shift report and obtained occurrence data are summarized in Table 5.1. Among the 173 WWD records, 39 of them (22.54%) have no nearby radar sensor that can provide data for further analysis. For the remaining 134 records that have nearby sensors, 37 of them have no data due to malfunction of the sensors. Also, sensors corresponding to 21 records didn't generate negative speeds due to two possible reasons: 1) missed calls where the sensor failed to detect WWD; and 2) inaccurate report information, where some WWD locations and times, recorded manually by the police, are not accurate.

Hence, there are 76 records in total that can potentially be used for parameter calibration in step 2. Taking some records as examples, Figure 5.1 summarizes the corresponding information contained after cross-verification of the police report and occurrence data. Since the number of records for calibration is limited, this study identifies the values of algorithm parameters as follows:

- Threshold of WWD occurring time: $a = 17{:}00$; $b = 11{:}00$;
- The threshold of distance to the off-ramp: $s = 2\ miles$;
- The threshold of 5-min volume: $Q = 200\ vehs$.

The obtained parameters for the Step 2 algorithm shall be updated when more field data are available. In Step 3, the information of each WWD record will be further validated with the probabilistic model. Specifically, the algorithm accounts for the probability of WWD vehicles confronting 0, 1, or 2 opposing vehicles by traveling from the off-ramp to the detector location. If the probability is less than the calibrated value, 10%, the corresponding negative speed record will be labeled as "potential false alarm". Table 5.2 shows examples of negative speed records used for the calibration.

**Table 5.2 The Probability of WWD Vehicles Confronted 0, 1, or 2 Opposing Vehicles**

| Detector ID | Time | P(X=0) | P(X=1) | P(X=2) | P(X=0,1,or 2) |
|---|---|---|---|---|---|
| I-15 MP257.8 | 21:49 | 0.39 | 0.37 | 0.17 | 0.93 |
| I-215W MP16.88 | 16:14 | 0.15 | 0.28 | 0.27 | 0.7 |
| I-15 MP299.95 | 6:55 | 0.29 | 0.36 | 0.22 | 0.87 |
| I-15 MP281.15 | 21:26 | 0.08 | 0.19 | 0.25 | 0.52 |
| I-15 MP304 | 19:20 | 0.02 | 0.08 | 0.15 | 0.25 |
| I-15 MP318.76 | 19:53 | 0.01 | 0.04 | 0.1 | 0.15 |
| I-15 MP257.8 | 19:59 | 0.01 | 0.03 | 0.07 | 0.11 |
| US 189_MP16.25 | 7:52 | 0.12 | 0.25 | 0.27 | 0.64 |
| Calibrated threshold of P(X=0,1, or 2): 0.1 | | | | | |

It shall be noted that the results of step 3 can be further used to re-calibrate the parameters in step 2. For example, the probability of WWD vehicles confronting 0 or 1 opposing vehicle in day time is 0. In addition, 60% of WWD vehicles having the probability of confronting 2 opposing vehicles in day time is 0. The remaining 40% of vehicles having the probability of confronting 2 opposing vehicles is close to 2%. However, the probability of all

WWD vehicles that may confront 0, 1, or 2 opposing vehicles in night time is significantly greater than 0. The highest probability reached 39%. That means that WWD is more likely to happen in the night time. Similarly, the results indicate that the distance to the ramp of all WWD records in the night time is less than 1 mile and WWD incidents are more likely to happen in a lane with traffic flow less than 130 vehicles/5-min.

# 6.0 EXPERIMENT OF ALGORITHM

## 6.1 Overview

For implementing the algorithm, our research team selected 3 locations located on I-215W (from MP14.06 – MP19.25), I-15 (from MP255 – MP259.1), and I-15 (from MP278.45 – 284.4) respectively. One-month data were downloaded for each detector located on the studied freeway segment, using the detected negative speed from downloaded data as an indicator to run the algorithm step-by-step. For this project, all cases are the case of Figure 4.1 (a). Step 2.2 (Threshold of distance to the off-ramp) of the threshold-based screening algorithm is an important indicator for the WWD study, but it is not useful for this project due to the majority of the Wavetronix radar installed within 2 miles of the off-ramp. There was no change after the threshold screening of step 2.2 for all 3 locations. The detailed analysis for each location is shown as follows.

## 6.2 Case study for Location 1

As shown in Figure 6.1, Location 1, located on I-215W from MP14.06 – MP19.25, has 17 detectors in total. One-month (01/09/2019 – 02/07/2019) data of each detector are downloaded for implementing the algorithm. All detectors and data availability information are shown in Table 6.1. It shows that 3 detectors have no data and the other 14 detectors have available data.

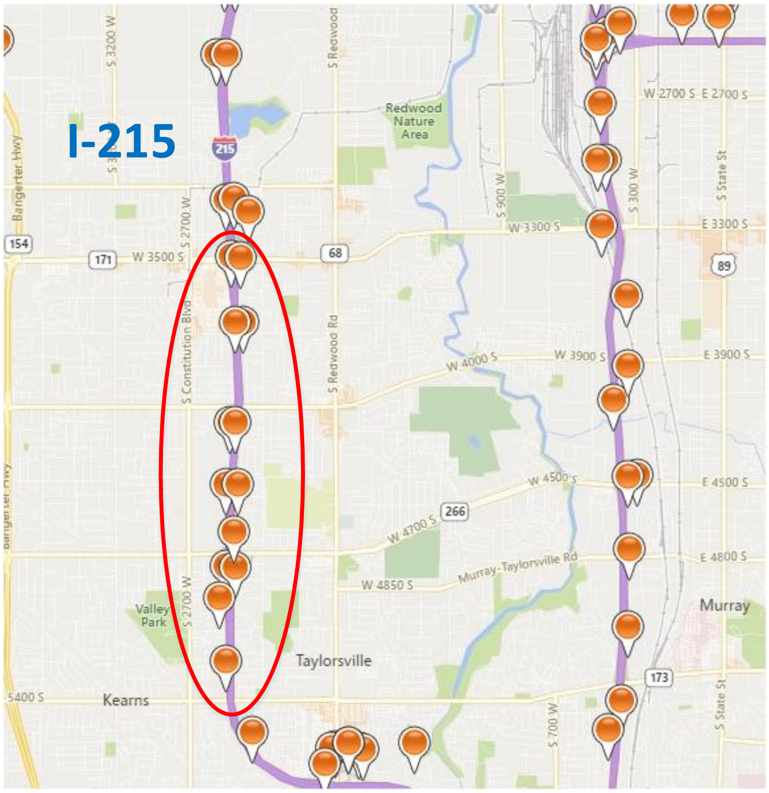


**Figure 6.1 Selected Detectors on I-215W in Location 1**

**Table 6.1 Detectors and Data Availability Information**

| Station ID | Road | Direction | Milepost | Data Availability |
|---|---|---|---|---|
| 100242 | I-215 | SB | 14.6 | No data |
| 100224 | I-215 | SB | 14.96 | No data |
| 100745 | I-215 | NB | 15.21 | Available |
| 100746 | I-215 | SB | 15.21 | Available |
| 100735 | I-215 | NB | 15.46 | Available |
| 100216 | I-215 | NB | 15.72 | Available |
| 100464 | I-215 | NB | 17.45 | No data |
| 100465 | I-215 | SB | 17.45 | Available |
| 100743 | I-215 | NB | 17.72 | Available |
| 100744 | I-215 | SB | 17.72 | Available |
| 100358 | I-215 | NB | 16.18 | Available |
| 100726 | I-215 | SB | 16.18 | Available |
| 100225 | I-215 | NB | 18.71 | Available |
| 100715 | I-215 | SB | 18.71 | Available |
| 100197 | I-215 | SB | 16.9 | Available |
| 100729 | I-215 | NB | 16.9 | Available |
| 100716 | I-215 | SB | 19.25 | Available |

208 negative speed records were obtained from all available detectors for running the screening algorithm step by step as follows:

- **Step 1: Preliminary data check**

  After the preliminary data check, we've obtained 40 negative speed records.

- **Step 2: Threshold-based screening algorithm**

  1. *Step 2.1**:** Threshold of WWD occurring time (17:00 < T < 11:00)*

     After the threshold of WWD occurring time check, we've obtained 34 negative speed records.

  2. *Step 2.2**:** Threshold of distance to the off-ramp (0 < D < 2 miles)*

     After the threshold of distance to the off-ramp check, we've obtained 34 negative speed records.

3. *Step 2.3: Threshold of traffic volume* ($0 < Q < 200\ vehs$)

After the threshold of traffic volume check, we've obtained 18 negative speed records.

- **Step 3: Probabilistic screening model**

After running the probabilistic screening model, we've obtained 9 WWD incidents, which would be WWD incidents as shown in Table 6.2. The detailed information for all 9 WWD incidents is shown in Appendix A.

**Table 6.2 The Probability of Vehicles Confronted 0, 1, or 2 Opposing Vehicles**

| Detector ID | Timestamp | D to off-ramp | 5-min Volume | P(X=0) | P(X=1) | P(X=2) | P(X=0, 1,or 2) |
|---|---|---|---|---|---|---|---|
| 100729 | 1/22/2019 4:12 | 0.5 | 61 | 0.01 | 0.04 | 0.09 | 0.14 |
| 100729 | 1/21/2019 0:02 | 0.5 | 47 | 0.02 | 0.07 | 0.15 | 0.24 |
| 100729 | 1/22/2019 0:20 | 0.5 | 50 | 0.02 | 0.07 | 0.15 | 0.24 |
| 100729 | 1/17/2019 1:32 | 0.5 | 44 | 0.02 | 0.09 | 0.16 | 0.27 |
| 100729 | 1/22/2019 0:22 | 0.5 | 46 | 0.02 | 0.09 | 0.17 | 0.28 |
| 100729 | 1/23/2019 2:45 | 0.5 | 38 | 0.05 | 0.15 | 0.22 | 0.42 |
| 100729 | 1/21/2019 1:18 | 0.5 | 31 | 0.08 | 0.20 | 0.26 | 0.54 |
| 100729 | 1/22/2019 1:28 | 0.5 | 21 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100729 | 1/24/2019 2:30 | 0.5 | 24 | 0.11 | 0.24 | 0.27 | 0.61 |

Table 6.3 shows that detector 100729 collects all 9 WWD incidents, which happened from 00:00 am – 4:30 am. So, the conclusion can be reached that the off-ramp near detector 100729 has a high risk of WWD and most of the WWD happened in the early morning. It also indicates that all WWD happened under low-traffic volume conditions.

### 6.3 Case study for Location 2

As shown in Figure 6.2, Location 2, located on I-15 from MP255 – MP259.1, has 14 detectors in total. One-month (01/09/2019 – 02/07/2019) data of each detector are downloaded for implementing the algorithm. All detectors and data availability information are shown in Table 6.3. It shows that 4 detectors have no data and the other 10 detectors have available data.

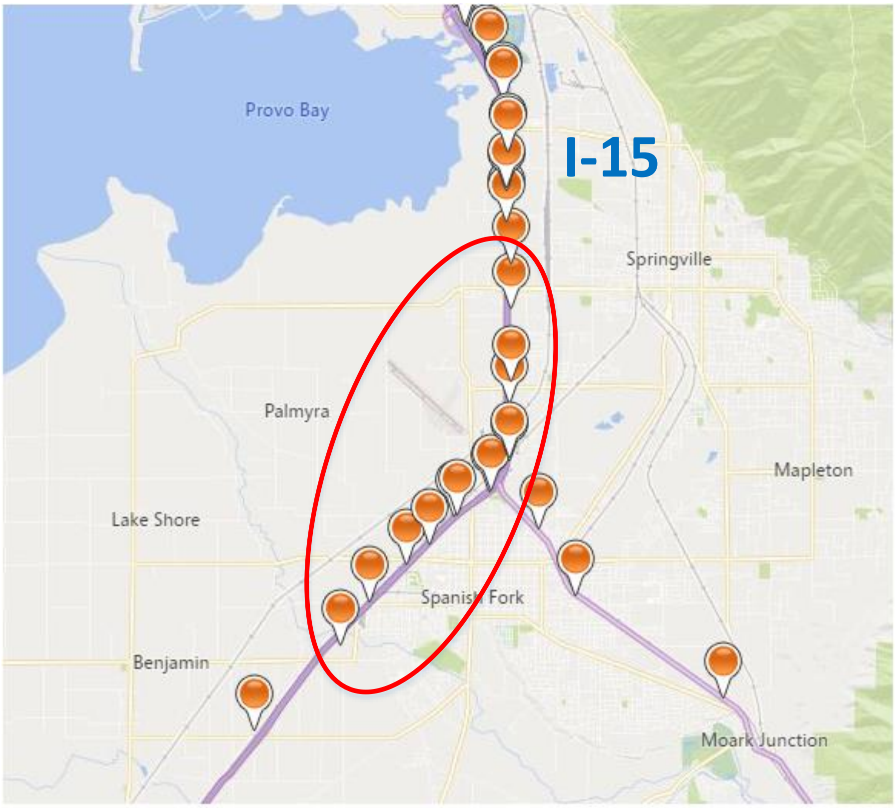


**Figure 6.2 Selected Detector on I-15 in Location 2**

**Table 6.3 Detectors and Data Availability Information**

| Station ID | Road | Direction | Milepost | Data Availability |
|---|---|---|---|---|
| 100598 | I-15 | NB | 255 | No data |
| 100527 | I-15 | NB | 255.54 | No data |
| 100526 | I-15 | NB | 256.15 | No data |
| 100492 | I-15 | NB | 260.1 | No data |
| 100523 | I-15 | NB | 257.16 | Available |
| 100524 | I-15 | SB | 257.16 | Available |
| 100521 | I-15 | NB | 257.44 | Available |
| 100522 | I-15 | NB | 257.44 | Available |
| 100520 | I-15 | SB | 257.8 | Available |
| 100519 | I-15 | NB | 257.8 | Available |
| 100525 | I-15 | NB | 256.48 | Available |
| 100530 | I-15 | NB | 258.6 | Available |
| 100493 | I-15 | NB | 259.86 | Available |
| 100518 | I-15 | NB | 259.1 | Available |

153 negative speed records were obtained from all available detectors for running the screening algorithm step by step as follows:

- **Step 1: Preliminary data check**

  After the preliminary data check, we've obtained 153 negative speed records.

- **Step 2: Threshold-based screening algorithm**

  1. *Step 2.1**:** Threshold of WWD occurring time (*$17{:}00 < T < 11{:}00$*)*

     After the threshold of WWD occurring time check, we've obtained 92 negative speed records.

  2. *Step 2.2**:** Threshold of distance to the off-ramp (*$0 < D < 2\,miles$*)*

     After the threshold of distance to the off-ramp check, we've obtained 92 negative speed records.

  3. *Step 2.3**:** Threshold of traffic volume (*$0 < Q < 200\,vehs$*)*

     After the threshold of traffic volume check, we've obtained 12 negative speed records.

- **Step 3: Probabilistic screening model**

  After running the probabilistic screening model, we've obtained 9 WWD incidents, which would be WWD incidents as shown in Table 6.4. The detailed information for all 9 WWD incidents is shown in Appendix B.

**Table 6.4 The Probability of Vehicles Confronted 0, 1, or 2 Opposing Vehicles**

| Detector ID | Timestamp | D to off-ramp | 5-min Volume | P(X=0) | P(X=1) | P(X=2) | P(X=0, 1,or 2) |
|---|---|---|---|---|---|---|---|
| 100522 | 1/23/2019 5:08 | 0.3 | 94 | 0.01 | 0.06 | 0.12 | 0.19 |
| 100518 | 1/12/2019 2:35 | 0.75 | 29 | 0.03 | 0.10 | 0.17 | 0.30 |
| 100524 | 1/9/2019 21:10 | 0.1 | 151 | 0.04 | 0.14 | 0.22 | 0.40 |
| 100522 | 1/13/2019 8:17 | 0.3 | 88 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100522 | 1/10/2019 0:47 | 0.3 | 50 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100524 | 1/20/2019 22:28 | 0.1 | 127 | 0.10 | 0.23 | 0.27 | 0.60 |
| 100522 | 1/21/2019 1:29 | 0.3 | 45 | 0.12 | 0.26 | 0.27 | 0.66 |
| 100520 | 1/23/2019 6:56 | 0.1 | 135 | 0.14 | 0.27 | 0.27 | 0.68 |
| 100520 | 1/15/2019 2:08 | 0.1 | 16 | 0.87 | 0.12 | 0.01 | 1.00 |

Table 6.4 shows that detector 100522 collected 4 WWD incidents, detector 100524 and detector 100520 collected 2 WWD incidents, and detector 100518 collected 1 WWD incident. Most of the WWD incidents happened from 21:00 pm – 7:00 am. So, the conclusion can be reached that the off-ramp near station 100522 had the highest risk of WWD and most of the WWD happened in the late night and early morning. It also indicates that all WWD happened under low-traffic volume conditions.

## 6.4 Case study for Location 3

As shown in Figure 6.3, Location 3, located on I-15 from MP278.45 – 284.4, has 24 detectors in total. One-month (01/09/2019 – 02/07/2019) data from each detector are downloaded for implementing the algorithm. All detectors and data availability information are shown in **Table 6.5**. It shows that 9 detectors have no data and the other 15 detectors have data available.

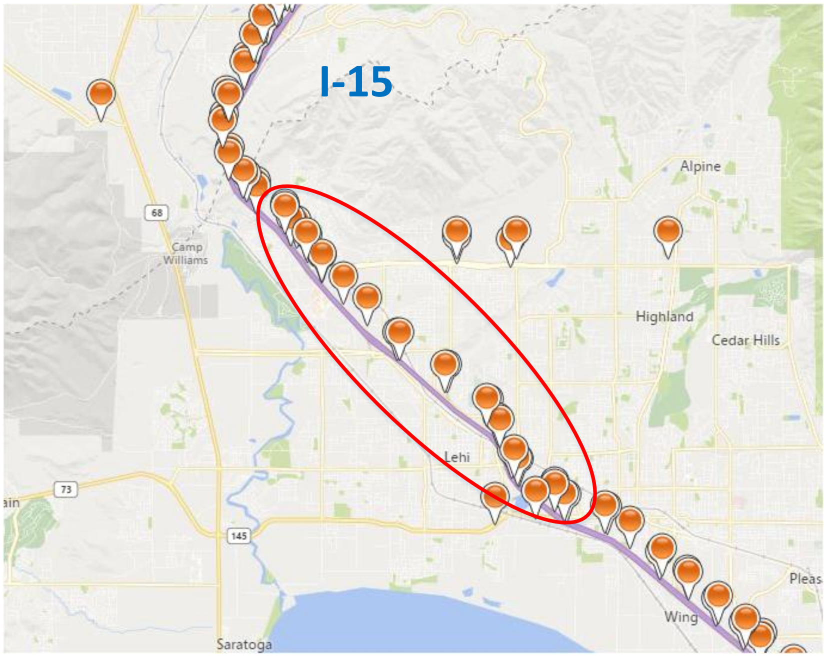


**Figure 6.3 Selected Detectors on I-15 in Location 3**

**Table 6.5 Detectors and Data Availability Information**

| Station ID | Road | Direction | Milepost | Data Availability |
|---|---|---|---|---|
| 100423 | I-15 | NB | 278.45 | Available |
| 100346 | I-15 | SB | 278.45 | Available |
| 100345 | I-15 | SB | 278.68 | Available |
| 100421 | I-15 | NB | 278.68 | Available |
| 100422 | I-15 | SB | 279.32 | Available |
| 100408 | I-15 | NB | 279.32 | Available |
| 100406 | I-15 | NB | 279.64 | Available |
| 100407 | I-15 | SB | 279.64 | Available |
| 100403 | I-15 | SB | 279.83 | Available |
| 100404 | I-15 | NB | 279.83 | Available |
| 100760 | I-15 | NB | 280.24 | Available |
| 100219 | I-15 | NB | 280.3 | No Data |
| 100761 | I-15 | NB | 281.15 | No Data |
| 100218 | I-15 | NB | 281.15 | Available |
| 100070 | I-15 | SB | 282 | Available |
| 100762 | I-15 | SB | 282 | Available |
| 100217 | I-15 | NB | 282.7 | Available |
| 100077 | I-15 | NB | 283.2 | No Data |
| 100698 | I-15 | SB | 283.7 | No Data |
| 100697 | I-15 | NB | 283.7 | No Data |
| 100763 | I-15 | NB | 284 | No Data |
| 100115 | I-15 | NB | 284 | No Data |
| 100696 | I-15 | NB | 284.3 | No Data |
| 100695 | I-15 | SB | 284.4 | No Data |

Station 100403 had 28056 negative speed records. This may have been a malfunction of this detector. These negative speed records are invalid for the study. 341 negative speed records were obtained from all other available detectors for running the screening algorithm step by step as follows:

- **Step 1: Preliminary data check**

  After the preliminary data check, we've obtained 161 negative speed records.

- **Step 2: Threshold-based screening algorithm**

  ***1.*** *Step 2.1**:** Threshold of WWD occurring time (17:00 < T < 11:00)*

After the threshold of WWD occurring time check, we've obtained 87 negative speed records.

2. *Step 2.2**:** Threshold of distance to the off-ramp* ($0 < D < 2\,miles$)

   After the threshold of distance to the off-ramp check, we've obtained 87 negative speed records.

3. *Step 2.3**:** Threshold of traffic volume* ($0 < Q < 200\,vehs$)

   After the threshold of traffic volume check, we've obtained 25 negative speed records.

- **Step 3: Probabilistic screening model**

  After running the probabilistic screening model, we've obtained 12 negative speed records, which would be WWD incidents as shown in **Table 6.5**. The detailed information for all 12 WWD incidents is shown in **Appendix 3**.

**Table 6.6 The Probability of Vehicles Confronted 0, 1, or 2 Opposing Vehicles**

| Detector ID | Timestamp | P(X=0) | P(X=1) | P(X=2) | P(X=0,1,or 2) |
|---|---|---|---|---|---|
| 100423 | 2/26/2019 4:30 | 0.01 | 0.03 | 0.08 | 0.11 |
| 100070 | 2/2/2019 5:57 | 0.01 | 0.04 | 0.09 | 0.13 |
| 100408 | 2/8/2019 22:37 | 0.02 | 0.06 | 0.13 | 0.21 |
| 100070 | 2/2/2019 5:35 | 0.02 | 0.08 | 0.16 | 0.26 |
| 100070 | 2/10/2019 20:54 | 0.03 | 0.09 | 0.17 | 0.29 |
| 100423 | 2/11/2019 23:28 | 0.04 | 0.13 | 0.21 | 0.37 |
| 100345 | 2/12/2019 0:23 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100408 | 2/4/2019 22:37 | 0.21 | 0.33 | 0.26 | 0.79 |
| 100070 | 2/27/2019 22:49 | 0.21 | 0.33 | 0.26 | 0.79 |
| 100070 | 2/23/2019 4:54 | 0.37 | 0.37 | 0.18 | 0.92 |
| 100423 | 2/10/2019 3:58 | 0.39 | 0.37 | 0.17 | 0.93 |
| 100070 | 2/23/2019 2:41 | 0.59 | 0.31 | 0.08 | 0.98 |

**Table 6.6** shows that detector 100070 collected 6 WWD incidents, detector 100423 collected 3 WWD incidents, detector 100408 collected 2 WWD incidents, and detector 100345 collected 1 WWD incident. All WWD incidents happened from 20:50 pm – 6:00 am. So, the conclusion can be reached that the off-ramp near detector 100070 had the highest risk of WWD

and most of the WWD happened in the late night and early morning. It also indicates that all WWD happened under low-traffic volume conditions.

### 6.5 Freeway Segment without Data

During the study, our research team found that detectors on some freeway segments can't collect data or just a few detectors can collect data. One freeway segment, located on I-215S (MP 7.25 – MP 10.62) illustrates this problem, as shown in Figure 6.4 The data availability information is shown in Table 6.7. It shows that all detectors have data collection problems.

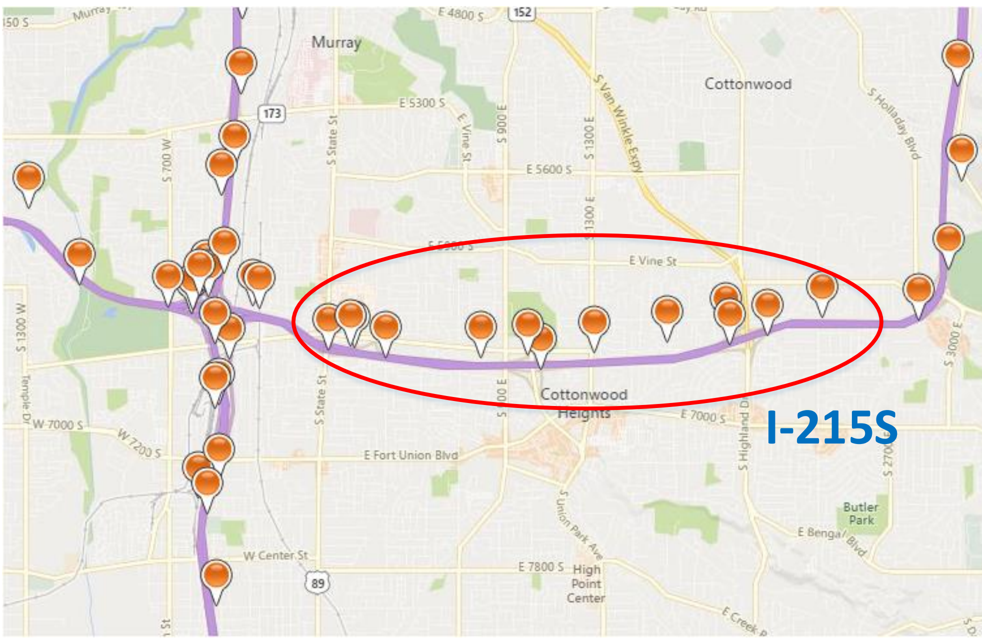


Figure 6.4 Selected Detectors on I-215S

**Table 6.7 Detectors and Data Availability Information**

| Station ID | Road | Direction | Milepost | Data Availability |
|---|---|---|---|---|
| 70 | I-215 | EB | 10.62 | No Data |
| 69 | I-215 | WB | 10.46 | No Data |
| 100712 | I-215 | WB | 10.78 | No Data |
| 68 | I-215 | EB | 10.18 | No Data |
| 67 | I-215 | WB | 9.62 | No Data |
| 65 | I-215 | WB | 9.31 | No Data |
| 66 | I-215 | EB | 9.16 | No Data |
| 64 | I-215 | WB | 8.87 | No Data |
| 73 | I-215 | WB | 8.23 | No Data |
| 75 | I-215 | WB | 7.76 | No Data |
| 74 | I-215 | EB | 7.98 | No Data |
| 76 | I-215 | EB | 7.59 | No Data |
| 100748 | I-215 | WB | 7.25 | No Data |

## 7.0 COUNTERMEASURES

Many research activities have focused on quantifying the WWD impact and assessing countermeasures and mitigation methods (Das et al., 2018b, 2018a; Lin et al., 2018; Ponnaluri, 2018; Pour-Rouholamin eta Zhou, 2016). Some traditional countermeasures for implementation include enlarged Wrong-Way signs, red reflective sheeting on sign supports, Wrong-Way signs with flashing light-emitting diodes (LEDs) around the border, pavement marking, and ramp design re-configuration. Those efforts often consume great amounts of time and funds. Hence, due to the limited resources from responsive agencies, it is vital to prioritize those sites having the most frequent WWD events for implementing countermeasures. Based on the experimental results and literature review of WWD countermeasures and mitigation methods, we recommend that the WWD countermeasures and mitigation methods should be implemented on locations with a high risk of WWD and they should be activated in the late night and early morning.

# 8.0 CONCLUSION

## 8.1 Summary

In this research, our research team proposed a multi-step screening algorithm for identifying WWD incidents and potential WWD false alarms by utilizing over 18 months of sensor data from the Utah Department of Transportation (UDOT) and Utah police WWD data. This first step focused on the preliminary evaluation of data quality and assessment of data completeness. After negative speeds of individual vehicles were identified, the second step applied a set of thresholds to examine the possibility of the false pulse. Several factors, such as the time, location, and current traffic flow rate when WWD occurred were considered. Then the last step utilized a probabilistic model to assess the possibility of WWD vehicles traveling from off-ramp to the detection location without confronting opposing vehicles. The key parameters of the proposed algorithm have been calibrated with the Utah police shift report that contains WWD crash records. Then the algorithm has been implemented to evaluate the sensor data on three freeway segments in Salt Lake City, I-15 and I-215.

## 8.2 Findings

Our results revealed that the proposed algorithm can function well to identify WWD incidents and potential WWD false alarm on the transportation network and to notify responsive agencies such as the state DOT which location needs additional countermeasures. The results show that most of WWD incidents happen in the late night and early morning because the traffic volume is low. It also indicates most wrong-way drivers enter the highway from the off-ramp and don't drive far from the off-ramp (most of them within 0.5 miles).

## 8.3 Limitations and Challenges

The proposed algorithm can function well to identify WWD incidents and potential WWD false alarms. But it may not be sufficient to support real-time WWD detections due to missed calls from radar sensors. The data quality of the detector is the basis for this research. In the study, we found that some detectors can't function well to collect data, such as data cannot be collected, partial data is collected, and data is incorrect.

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# APPENDIX A: DETAILED INFORMATION FOR WWD INCIDENTS OF LOCATION 1

## Table A.1 The Raw Data and Metrics in Location 1

| IntId | ExtId | Timestamp | LaneId | LaneNumber | Direction | Class | Speed | Length | Duration | Range | D to off-ramp | 5-min volumn | P(X=0) | P(X=0) | P(X=0) | P(X=0,1,or 2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100729 | 2310141 | 1/22/2019 4:12 | 1 | 1 | Northbound | 4 | -75.676 | 54.9727 | 2.14453 | 133.055 | 0.5 | 61 | 0.01 | 0.04 | 0.09 | 0.14 |
| 100729 | 2310141 | 1/21/2019 0:02 | 1 | 1 | Northbound | 2 | -70.195 | 20.7461 | 1.01172 | 130.055 | 0.5 | 47 | 0.02 | 0.07 | 0.15 | 0.24 |
| 100729 | 2310141 | 1/22/2019 0:20 | 1 | 1 | Northbound | 1 | -74.766 | 19.6172 | 0.91016 | 126.051 | 0.5 | 50 | 0.02 | 0.07 | 0.15 | 0.24 |
| 100729 | 2310141 | 1/17/2019 1:32 | 1 | 1 | Northbound | 3 | -70.156 | 38.875 | 1.70313 | 125.051 | 0.5 | 44 | 0.02 | 0.09 | 0.16 | 0.27 |
| 100729 | 2310141 | 1/22/2019 0:22 | 1 | 1 | Northbound | 5 | -74.348 | 155.012 | 5.76563 | 136.055 | 0.5 | 46 | 0.02 | 0.09 | 0.17 | 0.28 |
| 100729 | 2310141 | 1/23/2019 2:45 | 1 | 1 | Northbound | 3 | -76.168 | 45.4375 | 1.79688 | 130.055 | 0.5 | 38 | 0.05 | 0.15 | 0.22 | 0.42 |
| 100729 | 2310141 | 1/21/2019 1:18 | 1 | 1 | Northbound | 3 | -74.02 | 35.7188 | 1.5 | 126.051 | 0.5 | 31 | 0.08 | 0.20 | 0.26 | 0.54 |
| 100729 | 2310141 | 1/22/2019 1:28 | 1 | 1 | Northbound | 2 | -54.496 | 29.5313 | 1.73438 | 130.055 | 0.5 | 21 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100729 | 2310141 | 1/24/2019 2:30 | 1 | 1 | Northbound | 1 | -64.066 | 19.0898 | 1.04297 | 125.051 | 0.5 | 24 | 0.11 | 0.24 | 0.27 | 0.61 |

# APPENDIX B: DETAILED INFORMATION FOR WWD INCIDENTS OF LOCATION 2

## Table B.1 The Raw data and Metrics in Location 2

| IntId | ExtId | Timestamp | LaneId | aneNumbe | Direction | Class | Speed | Length | Duration | Range | D to off-ramp | 5-min volumn | P(X=0) | P(X=1) | P(X=2) | P(X=0,1,or 2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100522 | 325412 | 1/23/2019 5:08 | 8 | 1 | Southbound | 2 | -77.8867 | 20.3438 | 0.89844 | 235.098 | 0.3 | 94 | 0.01 | 0.06 | 0.12 | 0.19 |
| 100518 | 325461 | 1/12/2019 2:35 | 6 | 1 | Southbound | 3 | -71.8867 | 38.1719 | 1.63281 | 108.043 | 0.75 | 29 | 0.03 | 0.10 | 0.17 | 0.30 |
| 100524 | 325152 | 1/9/2019 21:10 | 4 | 1 | Southbound | 2 | -58.3281 | 23.7656 | 1.35547 | 86.0352 | 0.1 | 151 | 0.04 | 0.14 | 0.22 | 0.40 |
| 100522 | 325412 | 1/13/2019 8:17 | 4 | 1 | Southbound | 5 | -137.035 | 80.8984 | 1.6875 | 88.0352 | 0.3 | 88 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100522 | 325412 | 1/10/2019 0:47 | 8 | 1 | Southbound | 1 | -77.8867 | 11.6914 | 0.60156 | 224.094 | 0.3 | 50 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100524 | 325152 | 1/20/2019 22:28 | 4 | 1 | Southbound | 3 | -66.207 | 31.9219 | 1.52344 | 86.0352 | 0.1 | 127 | 0.10 | 0.23 | 0.27 | 0.60 |
| 100522 | 325412 | 1/21/2019 1:29 | 8 | 1 | Southbound | 1 | -77.8867 | 13.6328 | 0.66797 | 224.094 | 0.3 | 45 | 0.12 | 0.26 | 0.27 | 0.66 |
| 100520 | 325432 | 1/23/2019 6:56 | 1 | 1 | Southbound | 2 | -81.1289 | 28.6328 | 1.13281 | 116.047 | 0.1 | 135 | 0.14 | 0.27 | 0.27 | 0.68 |
| 100520 | 325432 | 1/15/2019 2:08 | 4 | 1 | Southbound | 5 | -136.008 | 141.832 | 2.89453 | 200.082 | 0.1 | 16 | 0.87 | 0.12 | 0.01 | 1.00 |

# APPENDIX C: DETAILED INFORMATION FOR WWD INCIDENTS OF LOCATION 3

## Table C.1 The Raw data and Metrics in Location 3

| IntId | ExtId | Timestamp | LaneId | aneNumbe | Direction | Class | Speed | Length | Duration | Range | D to off-ramp | 5-min volumn | P(X=0) | P(X=1) | P(X=2) | P(X=0,1,or 2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100423 | 301382 | 2/26/2019 4:30 | 5 | 5 | Northbound | 3 | -61.5273 | 42.6602 | 2.10547 | 186.078 | 0.4 | 66 | 0.01 | 0.03 | 0.08 | 0.11 |
| 100070 | 230926 | 2/2/2019 5:57 | 1 | 1 | Northbound | 1 | -29.0781 | 13.0625 | 1.74219 | 97.0391 | 0.15 | 80 | 0.01 | 0.04 | 0.09 | 0.13 |
| 100408 | 300671 | 2/8/2019 22:37 | 6 | 1 | Northbound | 3 | -75.9219 | 36.6719 | 1.49609 | 210.086 | 0.15 | 177 | 0.02 | 0.06 | 0.13 | 0.21 |
| 100070 | 230926 | 2/2/2019 5:35 | 1 | 1 | Northbound | 1 | -29.0781 | 11.125 | 1.56641 | 95.0391 | 0.15 | 62 | 0.02 | 0.08 | 0.16 | 0.26 |
| 100070 | 230926 | 2/10/2019 20:54 | 6 | 1 | Northbound | 0 | -51.1133 | 6 | 0.62109 | 165.066 | 0.15 | 104 | 0.03 | 0.09 | 0.17 | 0.29 |
| 100423 | 301382 | 2/11/2019 23:28 | 5 | 5 | Northbound | 3 | -90.707 | 30.2773 | 0.88672 | 185.078 | 0.4 | 61 | 0.04 | 0.13 | 0.21 | 0.37 |
| 100345 | 302540 | 2/12/2019 0:23 | 1 | 1 | Southbound | 2 | -74.1055 | 27.3984 | 1.19922 | 142.059 | 0.3 | 48 | 0.10 | 0.23 | 0.26 | 0.59 |
| 100408 | 300671 | 2/4/2019 22:37 | 6 | 1 | Northbound | 3 | -97.5156 | 41.1211 | 1.28516 | 212.086 | 0.15 | 85 | 0.21 | 0.33 | 0.26 | 0.79 |
| 100070 | 230926 | 2/27/2019 22:49 | 1 | 1 | Northbound | 2 | -118.586 | 44.3516 | 1.12891 | 94.0391 | 0.15 | 103 | 0.21 | 0.33 | 0.26 | 0.79 |
| 100070 | 230926 | 2/23/2019 4:54 | 6 | 1 | Northbound | 0 | -71.8594 | 6 | 0.44141 | 166.07 | 0.15 | 40 | 0.37 | 0.37 | 0.18 | 0.92 |
| 100423 | 301382 | 2/10/2019 3:58 | 5 | 5 | Northbound | 3 | -116.859 | 45.5078 | 1.03516 | 192.078 | 0.4 | 23 | 0.39 | 0.37 | 0.17 | 0.93 |
| 100070 | 230926 | 2/23/2019 2:41 | 6 | 1 | Northbound | 0 | -71.8594 | 6 | 0.44141 | 164.066 | 0.15 | 21 | 0.59 | 0.31 | 0.08 | 0.98 |